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# A STUDY TO DETERMINE THE WEIGHT AND PERFORMANCE CHARACTERISTICS OF VARIABLE GEOMETRY SPACECRAFT

VOL. I - SUMMARY

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## FOREWORD

This document is Volume I of a four-volume final report on "A Study to Determine the Weight and Performance Characteristics of Variable Geometry Spacecraft", and was prepared under NASA contract NAS 1-7675 with Langley Research Center by the Convair division of General Dynamics at San Diego, California. Mr. B. Z. Henry was the NASA Technical Monitor. The work was performed by the Maneuverable Spacecraft and Reusable Launch Vehicles Department which is managed by R. A. Nau. The program was managed by K. S. Coward, and the following made major contributions to the task:

| | |
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| Structural Analysis: | C. A. Garrocq |
| Dynamics: | B. J. Kuchta |

The various volumes of this report cover the following subjects:

| | |
|---|---|
| Volume I | Summary |
| Volume II | Vehicle Development |
| Volume III | Final Configurations and Flight Mechanics |
| Volume IV | Thermostructural Design, Subsystems, and Weights |

# 1.0 SUMMARY

The purpose of the study reported on in this document was to perform a preliminary design effort, including an evaluation of the performance, on various hypersonic lifting body concepts incorporating hard variable geometry features and providing for seven passengers and a crew of two. The purpose, further, was to investigate the effect upon the design of varying certain fundamental parameters and to determine the sensitivity of these variations on the operational characteristics. The spacecraft is boosted into a 262 n.mi. orbit by the Saturn IB where it will rendezvous with a large space station in a logistic role.

The contractor was provided three basic configurations - one in each of the hypersonic L/D classes of 1, 2, and 3, and was directed to provide at least one additional configuration in each class for the over-all study. Thus, a preliminary design effort was made on six vehicles, and the individual characteristics of each examined on the basis of as nearly consistent basic criteria and methods as possible.

An important result of the study is a realistic appraisal of the weight variation between the vehicles of the various L/D classes. An average of the two L/D = 1 vehicles showed a vehicle weight of 14,000 pounds; of the L/D = 2 a weight of 15,500 pounds; and the L/D = 3 a weight of 19,500 pounds. Thus it is seen that there is a weight difference of about 1500 pounds between the L/D = 1 and 2 classes, and a difference of about 4000 pounds between the L/D = 2 and 3 classes.

Vehicle sizing depended on the height requirements of seated personnel in the high L/D vehicles and, additionally, on the fore and aft spacing of the seats for the L/D = 1 vehicles.

While the study did not include a detailed comparison with fixed geometry lifting entry vehicles, the results of the study clearly indicate the advantages of variable geometry from the standpoints of handling qualities (provided by the high roll damping with wings extended), high lift coefficient capability for making the landing flare and float less critical, higher subsonic L/D for decreasing the sink rate in the landing approach, and improved visibility offered by the lower approach and landing attitudes.

## 2.0 INTRODUCTION

Recent studies have investigated, largely from an operational and engineering viewpoint, several different lifting reentry spacecraft approaches to an overall logistics/ ferry system. These spacecraft designs have encompassed hypersonic lift-drag ratios from about one to greater than three with provision for horizontal ground landing. Some of the results have indicated that the use of variable geometry features can provide useful flexibility and significant aerodynamic performance enhancement over the operating regime. These advantages accrue primarily from the partial decoupling of the aerodynamic performance requirements of the various flight modes the lifting spacecraft must traverse. Variable geometry, properly applied, should not unduly compromise the hypersonic performance of good aerodynamic design while providing favorable low-speed and tangential landing characteristics.

Various mode decoupling methods for spacecraft recovery, such as parachutes, the parawing concepts, propulsive lift, and rotors, are of interest and show, in some cases, potential for low touchdown velocities and attractive recovery system weights. Conventional tangential landing is also attractive, especially when it can be accomplished at prepared, fixed sites and with the flexibility to reach these sites under a variety of conditions. Such a capability is best accomplished when both high lift and high lift-drag ratios can be achieved.

The potential for significant decreases in crew stress associated with reduced reentry load factors for lift-drag ratios of one and above are of interest for man-in-the-loop systems. Low crew stress during reentry and landing may be of particular concern for multi-man missions such as space station crew rotation and ferry of non-astronaut type passengers, especially following periods of extended weightlessness or simulated low g environment during which adverse physiological effects may have been incurred. Further, the potential for increased longitudinal and lateral range and atmospheric maneuvering capability with increases in hypersonic lift-drag ratio make systems possessing such capability of interest. Increases in ranging and maneuvering capability significantly increase the ability to reach a preselected landing site following reentry and correspondingly can reduce the orbital waiting time preceeding the de-orbit maneuver. Further, the ability for ready landing site acquisition, safe flare characteristics, low touchdown speeds and short run out distances under conditions of good pilot visibility are particularly desirable for all-weather operational capability. Various applications of variable geometry features appear to make these performance characteristics achievable for a wide range of lifting spacecraft designs.

The study reported on in this four-volume document was performed in sufficient technical depth to enable valid determination of the advantages and disadvantages of variable geometry, such assessment being made on the basis of a careful evaluation of the aerodynamic, aerothermodynamic, structural, and weight characteristics, including the effects of mission profile.

## 3.0 GROUND RULES

The objective of the study was to investigate lifting body concepts incorporating hard variable geometry, and to determine sensitivities of varying the design parameters; perform a conceptual design effort on spacecraft in three hypersonic L/D classes - 1, 2, and 3; and to examine the technology developments required to further design the vehicles.

The guidelines for the 10 month study specified that the vehicles were to be in logistic support of a large space station in a 262 n.mi. circular orbit, providing for a crew of two and seven passengers with 500 pounds of return cargo. The launch vehicle was to be an uprated Saturn IB, unmodified except for local attachment of the adapter section. The vehicles were to be capable of performing a horizontal ground landing. The thermal protection system was to be either radiative or ablative, depending on the aerodynamic heating indicated by the detailed analysis of each candidate vehicle. NASA was to supply aerodynamic data on one vehicle in each of the three hypersonic L/D classes.

A detailed breakdown, in abbreviated form, of the contract statement of work which amplifies the ground rules mentioned above, is contained in Volume II of this report. These ground rules were changed at mid-term of the study program to include a "final" preliminary design of an additional three vehicles which had been "alternates" in the original work statement.

# 4.0 VEHICLE DESIGN AND WEIGHTS

A broad spectrum of variable geometry entry spacecraft was assembled at the beginning of the study, consisting of all the concepts currently available at that time. New configurations were also generated. During the study, these were reduced to six different entry spacecraft types, two in each of the approximate hypersonic L/D classes of 1, 2, and 3. The final shapes and sizes resulting from the design iterations are shown in Figures 1a through 1f. The concepts designated "A" are derivatives of the NASA configurations, while those designated "B" are those generated by the contractor. The prefix indicates the L/D class. A component key is provided to aid in examining the layouts. The entry spacecraft are shown with their associated cargo modules and adapters. Docking with the space station in orbit is made by engaging the aft face of the cargo module with docking bars and a docking hatch in the space station. Personnel access to the station is via a hatch in the entry spacecraft base.

The entry spacecraft are all sized by the internal clearance requirements of the 9 men and 500 pound return cargo specified for the orbital logistics mission. The physical dimensions and the seated attitude of the personnel are the primary sizing criteria in all the vehicles. The required subsystems can be installed within the vehicle sized by the personnel envelope. Ballast must be used in certain of the vehicles to provide a c.g. location within aerodynamic constraints. As many hatches as feasible are installed, preferably one to each row of passengers, in order to facilitate ingress and egress.

The variable geometry wings in the final vehicles are predominantly of the switchblade type (shown for entry Spacecraft 1B, 2A, 2B, and 3B). A folding wing concept is used in Vehicle 1A and a skew wing in Vehicle 3A.

The adapter section connects the spacecraft to the cargo module, and (with the exception of Vehicle 2B) includes the solid propellant retro-rockets and the abort rockets. Abort off-the-pad is the design case for the retro- as well as abort rockets. Recovery is made by extending the wings at apogee and making a glide landing. An emergency parachute system is also provided, although the necessity for this is questionable.

The cargo module is arranged to provide for docking with the space station at the aft end of the module and incorporates the maneuvering rocket nozzles for this maneuvering. A tunnel between the spacecraft and the docking point and space for the upflight cargo is provided.

Figure 2 depicts the six spacecraft installed on the Saturn IB booster. The vehicle weight trends are summarized in Figure 4 and 5. Table I presents the aerodynamic reference dimensions, areas, centers of gravity, and airfoil sections.

The operational sequence of major events from launch through orbit and return to earth landing is shown in Figure 3. The figure shows the major events of the normal up-flight, normal return, off-the-pad abort, and emergency parachute operation.

# 5.0 AERODYNAMICS AND PERFORMANCE

## AERODYNAMICS

The aerodynamic characteristics of all the vehicles were evaluated across the speed regime using experimental data as the basis whenever available. Experimental data were available for the 1A, 2A, 2B and 3A vehicles. In the absence of experimental data, accepted analysis procedures such as modified Newtonian theory were used.

Preliminary vehicle designs and their associated aerodynamic characteristics were used as the basis for performing sensitivity and tradeoff studies using a vehicle synthesis computer program. The effects of variations in parameters, such as wing span, incidence and high lift devices on the aerodynamic, performance, and weight characteristics were evaluated. The lack of specific performance requirements which had to be met for any combination of parameter variations reduced the significance of the sensitivity studies.

The trimmed subsonic and hypersonic characteristics of the six spacecraft are summarized in Table II. The hypersonic characteristics are typical in that the lift and angle of attack at maximum L/D decrease with increasing hypersonic L/D. All of the vehicles except 3A have relatively high maximum lift capability (trimmed $\alpha > 40$ degrees). The subsonic maximum L/D values vary from 4.5 to greater than 8.0 with lift coefficients at maximum L/D from 0.4 to 0.7. All of the vehicles are directionally stable at both the subsonic and hypersonic maximum L/D conditions.

In addition to improving the basic subsonic longitudinal characteristics, the use of variable geometry improves the handling qualities — particularly the roll damping characteristics. Switch blade type variable geometry offers potential as a means of static margin control, including possible elimination of any transonic pitch-up and improvements in directional stability.

## FLIGHT PERFORMANCE

The launch vehicle is an uprated Saturn 1B. A launch trajectory with an injection altitude of 60 n. mi. was selected to improve the abort load factor and heating characteristics. The injection velocity is such that the vehicle is placed in an elliptical orbit with an apogee at 100 n. mi. The vehicle circularizes in the 100 n. mi. parking orbit and then transfers to the 262 n. mi. design orbit.

There are three critical launch abort conditions: on-the-pad, maximum load factor condition and maximum aerodynamic heating condition. The procedure for the on-the-pad abort condition consists of 1) separation and acceleration with high thrust abort rockets, 2) a 180 degree roll maneuver to an upright position, 3) wing deployment, and 4) glide to a landing strip. This maneuver was investigated taking into account the longitudinal dynamics and was found to be feasible. A typical time history of the performance after apogee including the wing deployment is presented in Figure 6. An autopilot commanding a given flight path angle was used in the simulation. These results, though determined for the abort condition, indicate that wing deployment in a normal entry should be no problem as far as flight characteristics are concerned.

The maximum pullout load factor occurs for abort from a velocity of approximately 10,000 fps. An investigation indicated that the pullout load factor could be reduced by modulating the lift from maximum lift to a value at maximum L/D or lower. The maximum pullout load factor was determined for each of the six vehicles including lift modulation, and the results are presented in the table below:

| Velocity at Abort Initiation ⟶ | 10,000 fps | 16,000 fps |
|---|---|---|
| Vehicle | Max. Pullout Load Factor g | Max. Lower Surface Temp. °R |
| 1A | 5.45 | 3200 |
| 1B | 5.65 | 3160 |
| 2A | 5.90 | 3860 |
| 2B | 5.95 | 3500 |
| 3A | 5.62 | 3840 |
| 3B | 4.8 | 3380 |

The maximum abort heating occurs for abort at a velocity of 16,000 fps. Trajectory and aerodynamic heating analyses indicated that, with trajectory modulation, there was a slight reduction in lower surface heating, but a large increase in upper surface and side heating. It was concluded that even with trajectory modulation the temperatures on the lower surface and the fins were marginal with respect to an insulation system, and ablation should be used on these surfaces and a maximum lift trajectory utilized.

Entry performance was determined for each of the spacecraft. An investigation of the effect of entry angle on cross range, retro-weight and TPS weight led to the selection of a nominal -2 degree entry angle at 400,000 feet. The nominal maximum cross-range maneuver consists of flight at maximum L/D, a bank angle of 0 degree through pullout, constant altitude transition by varying the bank angle and finally, flight at a 45 degree bank angle. The effects of hypersonic viscous interaction on the aerodynamics were included in the entry performance analyses. The resulting maximum cross range capability of each of the vehicles is tabulated on the next page.

| Vehicle | Maximum Cross Range Viscous Effects (n. mi.) | Maximum Cross Range Non-Viscous (n. mi.) |
|---|---|---|
| 1A | 940 | 1100 |
| 1B | 840 | 1050 |
| 2A | 1450 | 1750 |
| 2B | 1620 | 2000 |
| 3A | 2940 | 3700 |
| 3B | 2780 | 3400 |

The landing performance was evaluated for each of the final vehicles. The landing maneuver starts from the wings deployed steady glide with a flare maneuver to a shallow flight path angle float condition, a five-second float followed by touchdown and runout. Tabulated below are the significant landing parameters for each of the six vehicles.

| Vehicle | Glide R/S (fpm) | $C_{L_{TD}}$ | $\alpha_{TD}$ (deg) | $V_{TD}$ (kts) |
|---|---|---|---|---|
| 1A | 5300 | 0.70 | 6.5 | 167 |
| 1B | 4500 | 0.70 | 7.5 | 151 |
| 2A | 2300 | 0.70 | 9.0 | 152 |
| 2A (flaps) | 2400 | 0.85 | 10.5 | 133 |
| 2B | 1700 | 0.40 | 2.0 | 178 |
| 2B (flaps) | 1900 | 0.65 | 5.5 | 142 |
| 3A | 3800 | 0.70 | 17.5 | 135 |
| 3A (flaps) | 3700 | 0.80 | 17.5 | 127 |
| 3B | 2550 | 0.70 | 10.5 | 138 |

If, for any reason, the wings should fail to deploy, it is expected that the landing characteristics would be generally similar to those of the lifting body research vehicles currently flown. In this emergency, the low wing vehicles must land with gear retracted because the wing, in the retracted position, interferes with the gear extension.

## 6.0 AERODYNAMICS

The aerothermodynamic analysis was performed using a General Dynamics Convair division aerodynamic/structural heat program and a NASA-developed reaction kinetics ablator program. Thermal protection system (TPS) thicknesses were determined for an insulation TPS on the upper surface, an ablator TPS on the lower surface, and ablator TPS for stagnation regions.

Figure 7 presents the peak lower surface temperatures during abort. Every spacecraft reached or exceeded the coated Columbium temperature limit during abort. These abort temperatures indicated the need for an ablator TPS on the lower surface. Figure 8 presents the ablator TPS thermodynamic model analyzed and Figure 9 the insulation model. Figure 10 shows the results of the ablator sizing calculations. Structural temperature-time histories, defined for each configuration from entry through landing run-out, were used to indicate insulation requirements.

Upper surface peak temperatures are shown in Figure 11. Configuration 2B required TD-NiC over the first seven feet. All other configuration temperatures indicated the use of super alloys, René 41 and L605.

The aerothermodynamic analysis indicated that present technology is adequate to permit development of the spacecraft under consideration. However, a technology development program is recommended to increase the accuracy of the heat transfer rate prediction and the sizing and selection of the TPS. Particularly important is the problem of boundary layer transition from laminar to turbulent flow.

## 7.0 THERMOSTRUCTURAL DESIGN

Body Shell. A thermally protected primary structure, with a peak skin temperature of 200°F, is proposed for all six study spacecraft. This selection is based on environmental control requirements, since the major portion of the body shell is intended for personnel occupancy. Figure 12 depicts a schematic of the thermal protection concept as applied to Vehicle 2A (baseline) which features an ablative system on the lower (or windward) surface, and a radiative system on the sides and upper (or leeward) surfaces. Development by Convair under Air Force contracts and independent research programs give confidence in the feasibility of design of cover panels and insulation in this type of system for a life of 100 flights.

A frame supported, stiffened skin, semi-monocoque arrangement for the primary structural shell is used. This applies to all six of the study spacecraft. The dominant load criterion is given by the cabin pressurization applied to the non-circular cross-section of the body shell.

Wing. The basic structure and pivot concepts are similar to the F-111 and are typical for all the "switchblade" wing configurations of Spacecraft 1B, 2A, 3A, and 3B. The concepts are also applicable to the "skew" wing of Spacecraft 3A except for the differences inherent in the wing continuity of this configuration. A wide-column, stringer stiffened skin concept is employed in the torsion/bending box which forms the primary load-carrying structure. Selection of the vertical pin pivot, a direct adaptation of the F-111 arrangement, was made, after study of a spectrum of pivot concepts, on the basis of minimum weight, minimum space requirements, and minimum technical risk. A problem in the "hot" wing versions of Spacecraft 2A and 3A concerns the sealing at the leading and trailing edges to inhibit flow and consequent severe heat transfer rates between the wing and body structure. The difficulty in sealing is due to thermal distortion of the wing when stowed, and elastic oscillations when released for deployment. In the event that the sealing problems prove intractable, the adoption of thermal protection over the stowed wings is entirely feasible. An equally difficult problem exists for internally stored wings wherein the detail design of doors (particularly for partial wing deployment) requires development.

Elevons and Horizontal Tail Surfaces. An ablative protected concept is required for all study spacecraft due to lower surface heating rates which exceed the capability of coated columbium cover panels. Ablative protection of all surfaces is proposed since this is an adaptation of the flight proven "PRIME" arrangement, and since tests on an elevon by Convair have indicated severe problems in a transition from a lower surface ablative system to an upper surface radiative system. An all ablative thermal protection system is selected for the horizontal tail surfaces and for similar surfaces which have significant "rollout" (such as 1B and 3A) for all six study spacecraft.

Vertical Fins and Rudders. Side surface temperatures on these components are not expected to exceed 1600°F. A hot structure concept is therefore proposed. A system of links attaches the fin to the body shell to isolate the cool body from the hot fin and to accommodate differential thermal expansions.

## 8.0 TECHNOLOGY

There are no technological problems unique to variable geometry spacecraft. The "technology" problems mentioned below are more in the nature of development problems rather than those requiring a step improvement in technology.

In configuration development, a need exists for more definitive data on the crew member space and orientation requirements as determined by tolerance to on-the-pad abort accelerations, ingress and egress. Such problems as on-the-pad abort warning time, accessibility for maintenance, and provision for emergency parachute operation (if indeed a parachute is required and if in fact it can land the spacecraft safely) are examples of problem areas requiring attention.

Aerodynamic technology requires experimental work to determine the characteristics of ablation-roughened surfaces, free-flight testing to investigate the dynamics of wing deployment, a better determination of the rotary stability derivatives, hypersonic control effectiveness, hypersonic viscous effects, and boundary layer transition. Performance work should involve a study of the Saturn boost flight path to determine the feasibility of a lower trajectory to improve the abort situation, and to determine the applicability of possibly other boosters.

Greater effort must be made in the field of aerothermodynamics from the standpoint of boundary layer transition, turbulent boundary layer heat transfer analysis methods, upper surface heat transfer data, shock wave impingement phenomena, and radiation protection system analysis problems.

Thermostructural design requires greater knowledge of such fundamental areas as ablation stability, refurbishment simplification, joining techniques, and treatment of discontinuities such as hatches.

## 9.0 CONCLUSION

This preliminary design study has shown that the use of "hard" variable geometry is feasible within current state-of-the-art for application to lifting entry vehicles across the hypersonic L/D spectrum. Realistic vehicle size, weight and performance characteristics were obtained for two candidate configurations in each of three hypersonic L/D classes. The advantages of variable geometry are the significant performance improvements that can be obtained both at subsonic and transonic speeds. Specific advantages are:

a. Ability to design for high hypersonic L/D by decoupling the low speed regime from the high speed regime.

b. Improved handling qualities because of much greater roll damping.

c. High subsonic L/D for better approach and landing characteristics.

d. High touchdown lift coefficient for better flare characteristics and lower touchdown speeds.

e. Improved landing visibility.

f. Stability margin and trim control for switchblade wings.

g. Clean aerodynamic surfaces, i.e., no ablator roughness.

h. Improved pad abort capability.

i. Lower planform area offers relief for booster loads.

j. Certain instrumentation might be located in the wings which could be deployed in orbit.

k. The development risk can be reduced.

l. Variable geometry offers the possibility for powered trainer vehicles.

Although variable geometry is feasible in all L/D classes, it was found that it is more compatible with medium and high hypersonic L/D vehicles than low L/D vehicles. The performance improvements and advantages cited above can be obtained with little or no weight penalty and with only a small increase in overall system complexity. In addition, there are no major technological problems associated with the variable geometry aspect.

Table I. Vehicle Geometry, Center of Gravity, and Airfoil Sections

| ITEM | VEHICLES | | | | | |
|---|---|---|---|---|---|---|
| | 1A | 1B | 2A | 2B | 3A | 3B |
| AERODYNAMIC | | | | | | |
| Reference length, ft | 29.90 | 25.75 | 39.20 | 42.00 | 50.00 | 55.00 |
| Reference span, ft | 11.72 | 13.30 | 11.16 | 10.16 | 11.80 | 11.82 |
| Reference area, $ft^2$ | 205.00 | 252.00 | 286.60 | 332.00 | 378.30 | 455.00 |
| CENTER OF GRAVITY LOCATION | | | | | | |
| Wing in, Sta. | 182.0 | 208.6 | 286.9 | 254.0 | 396.6 | 377.3 |
| Wing out, Sta. | 182.0 | 205.6 | 283.1 | 250.5 | 396.6 | 372.0 |
| AIRFOIL SECTION | Gott. 711 | NACA 4412 | St. Cyr. 156 | NACA $64_3$-618 | St. Cyr. 156 | NACA 4415 |

Table II. Aerodynamic Data Comparison

| ITEM | VEHICLES | | | | | |
|---|---|---|---|---|---|---|
| | 1A | 1B | 2A | 2B | 3A | 3B |
| HYPERSONIC | | | | | | |
| Max L/D | 1.4 | 1.25 | 1.79 | 2.05 | 2.95 | 2.68 |
| $C_L$ @ Max L/D | 0.340 | 0.345 | 0.197 | 0.185 | 0.140 | 0.092 |
| $\alpha$ @ Max L/D, deg | 19 | 21 | 13.5 | 16 | 9 | 8.5 |
| $C_{L_{Max}}$ | 0.66 | 0.63 | 0.71 | 0.65 | 0.46 | 0.64 |
| $\alpha$ @ $C_{L_{Max}}$, deg | 35.5 | 41.5 | 45 | 45 | 24 | 45 |
| $C_{n_\beta}$ @ max L/D | 0.0004 | 0.0003 | 0.0042 | 0.0009 | 0.0012 | 0.0001 |
| SUBSONIC | | | | | | |
| Max L/D | 4.5<br>6.0[1] | 4.7<br>4.6[1] | 7.8 | 8.9 | 5.0 | 6.3 |
| $C_L$ @ Max L/D | 0.54<br>0.70[1] | 0.66<br>0.66[1] | 0.5 | 0.4 | 0.4 | 0.5 |
| $\alpha$ @ Max L/D, deg | 4.0<br>10.0[1] | 7.0<br>10.0[1] | 3.0 | 5.0 | 7.0 | 5.0 |
| $C_{n_\beta}$ @ Max L/D | 0.003 | 0.004 | 0.011 | 0.0025 | 0.001 | 0.003 |

[1] Test data obtained late in study program (See Appendix A of Volume III).

COMPONENT KEY -- ENTRY SPACECRAFT AND ADAPTERS

| Key Number | Component Name |
|---|---|
| 1 | Batteries |
| 2 | Inverters Main (2) |
| 3 | Inverters Control System (2) |
| 4 | Busses Main (2) |
| 5 | Solenoid Switches (10) |
| 6 | Nose Landing Gear and Compartment |
| 7 | Radar Beacons |
| 8 | Transceivers |
| 9 | Voice Control Center |
| 10 | Unified S-Band System |
| 11 | Telemetry Package |
| 12 | Digital Command Decoder |
| 13 | HF Whip Antenna |
| 14 | VHF Antennas (2) |
| 15 | S-Band Antennas (2) Radar Beacon Antennas (2) |
| 16 | Inertial Measuring Unit System |
| 17 | Digital Computer |
| 18 | Time Reference System |
| 19 | Horizon Sensors (2) |
| 20 | Radar Altimeter |
| 21 | Back-Up Guidance Package |
| 22 | Flight Control Electronics |
| 23 | Cockpit Controls & Instrument Panels |
| 24 | Pilot in Pressure Suit |
| 25 | Crewman in Pressure Suit |
| 26 | Passenger in Pressure Suits (7) |
| 27 | Seat, Personal Effects, Survival Kit, Hygiene, Intercomm Units & Suit Connectors |
| 28 | Maps, Manuals and Logs |
| 29 | Food and Container |
| 30 | Water and Container |
| 31 | Liferaft, Radio, and Equipment |
| 32 | Central Survival and Medical Kit |
| 33 | Repair and Tool Kit |
| 34 | Emergency Parachute System |
| 35 | Entry Attitude Control Thruster (10) or (12) |
| 36 | Entry Attitude Control Propellant Tanks (2) or (4) |
| 37 | Entry Attitude Control Pressurant Tanks (2) |
| 38 | Main Landing Gear |
| 39 | ECS - Thermal Control System |
| 40 | ECS - Contaminant Control System |
| 41 | ECS - Atmosphere Control and Storage System |
| 42 | Hydraulic Subsystem Pumps and DC Motors (2) |
| 43 | Hydraulic Reservoirs (2) and Manifold |
| 44 | Return Cargo Space |
| 45 | Variable Geometry Wing Extension Mechanism & Pivots |
| 46(X) | Exit and Entry Hatch and Total Number Provided |
| 47 | Hatch to Cargo Module |
| 48 | Entry Vehicle/Adapter-Module-Booster Umbilical Disconnect |
| 49 | Ejectable Canopy Visor |
| 50 | Elevon Actuators |
| 51 | Rudder Actuators |
| 52 | Ballast |
| 53 | DOACS Thruster Group (4) |
| 54 | Abort Rockets (2) |
| 55 | Retro Rockets (5) |
| 56 | Fuel Cells |
| 57 | Reactants For Fuel Cells |

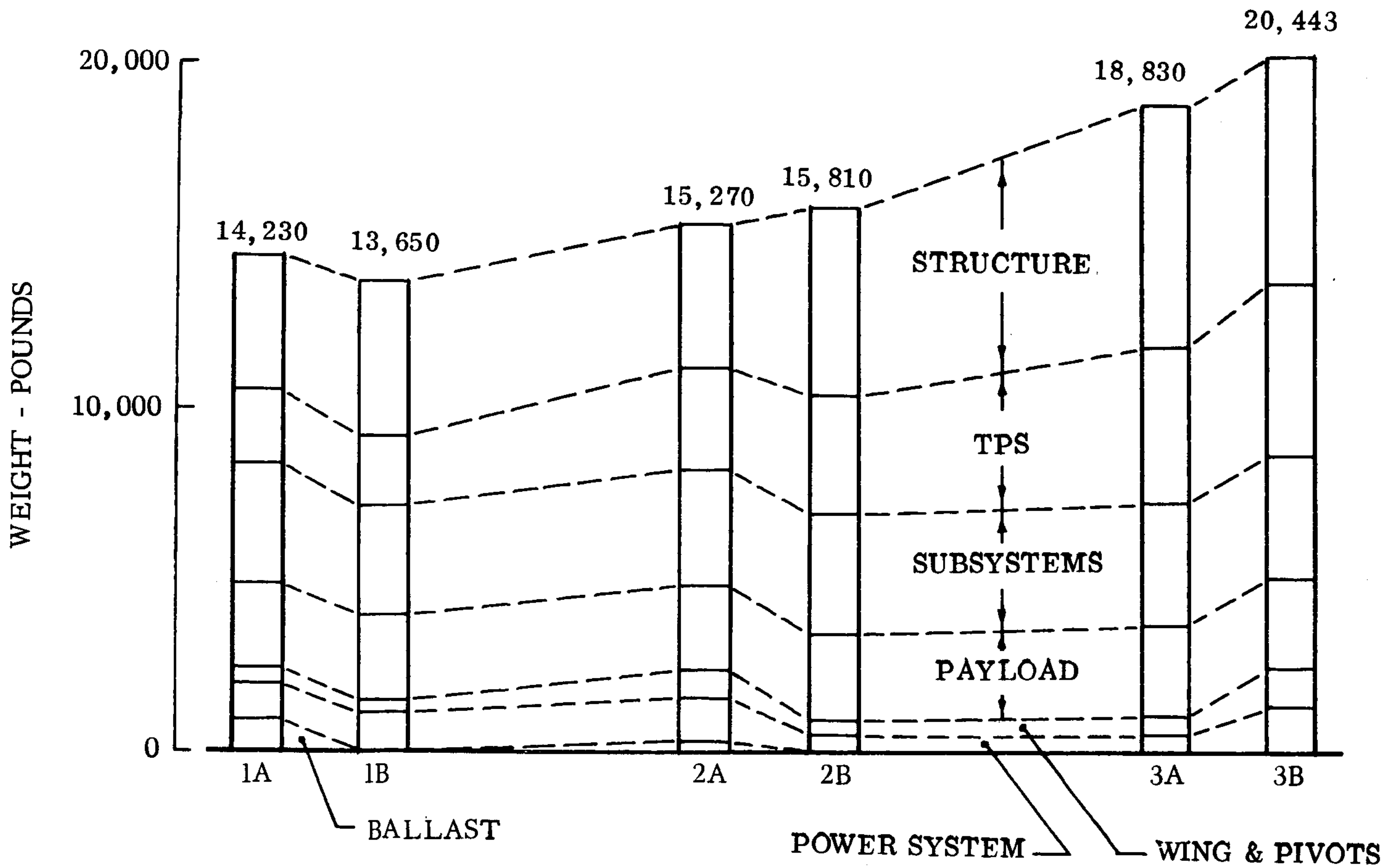



Figure 5. Entry Vehicle Weights

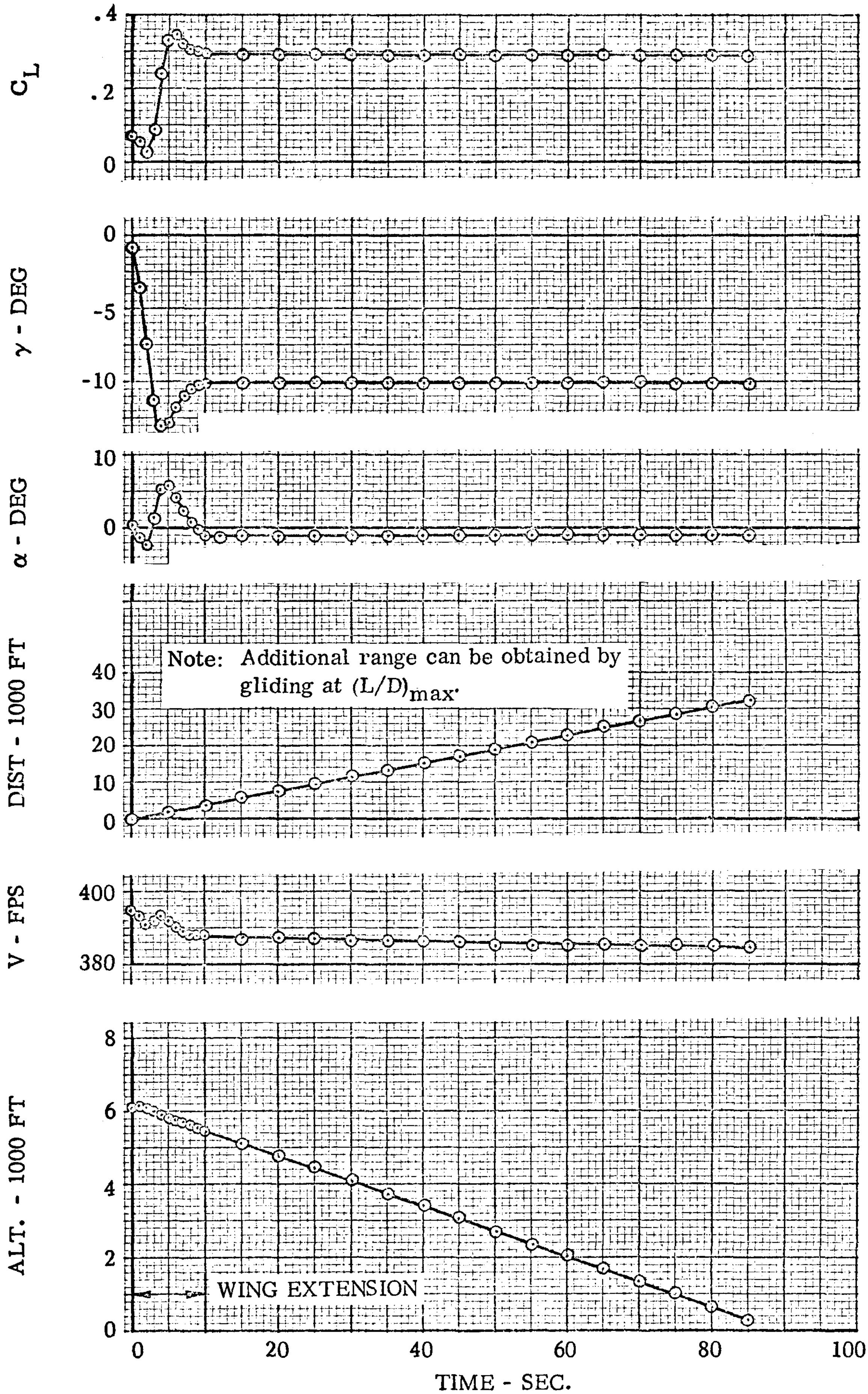



Figure 6. Pad Abort Trajectory Time History from Start of Wing Deployment to Landing Approach, Vehicle 2A

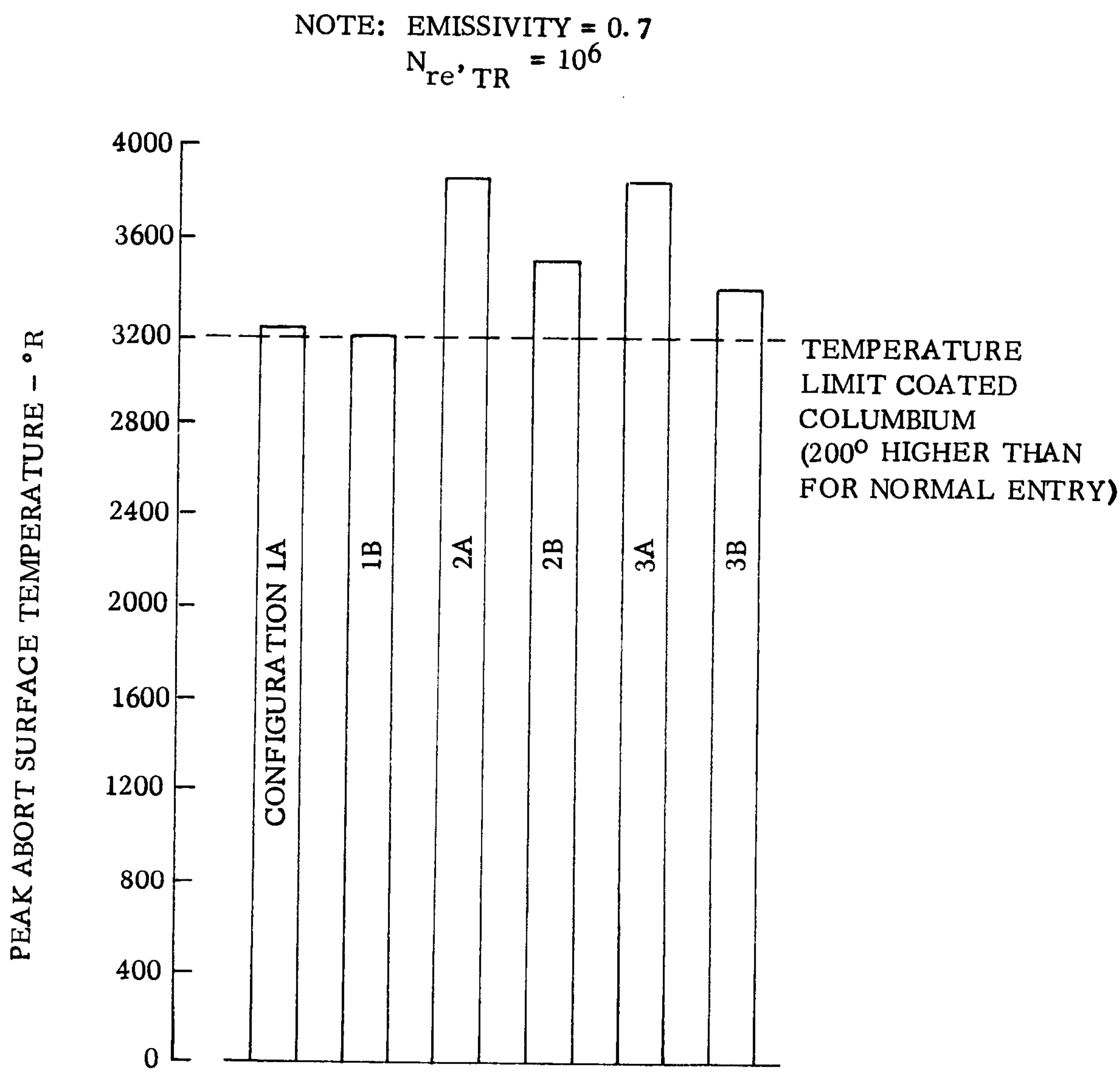



Figure 7. Abort Peak Surface Temperatures

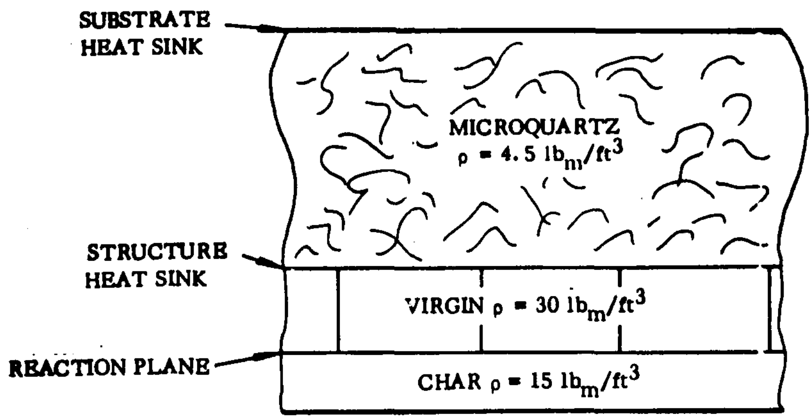



Figure 8. Ablator Schematic and Thermodynamic Model

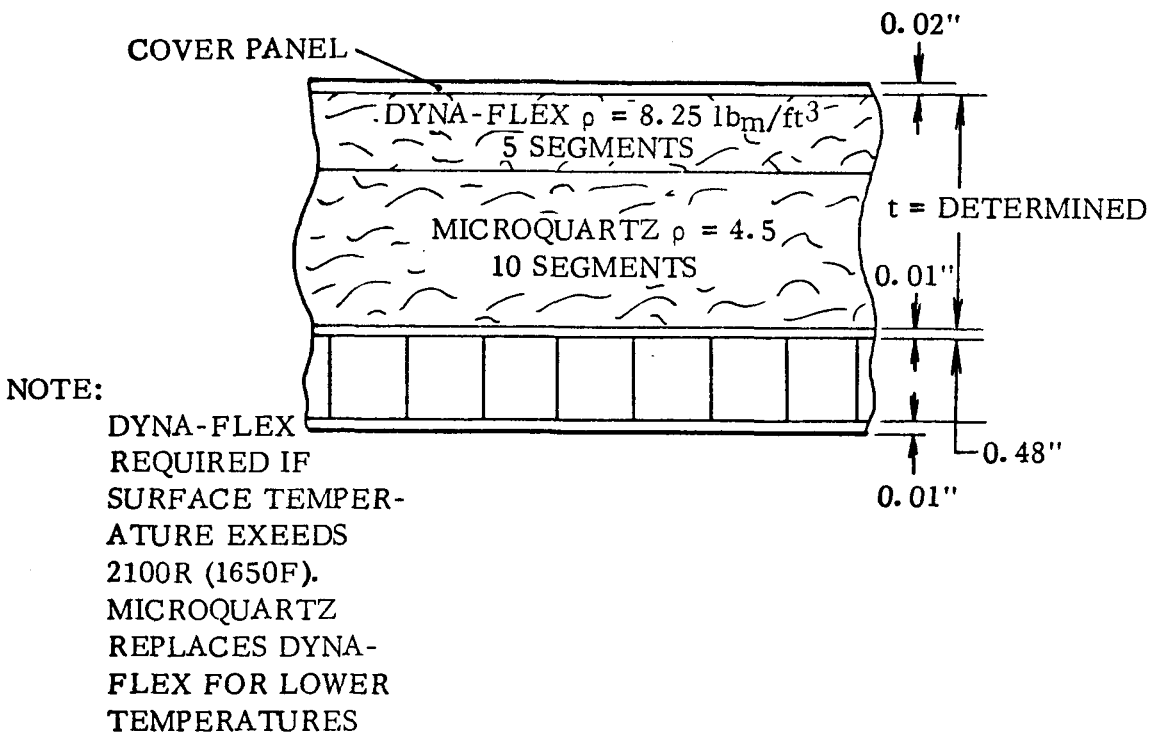



Figure 9. Upper Surface TPS Thermodynamic Model

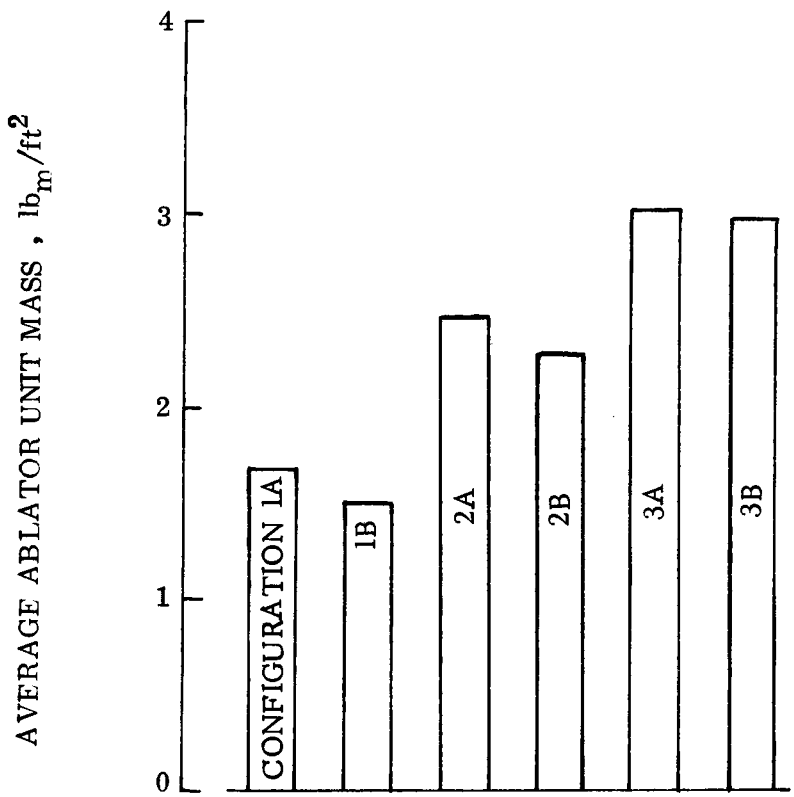



Figure 10. Average Unit Ablator Mass, Lower Surface

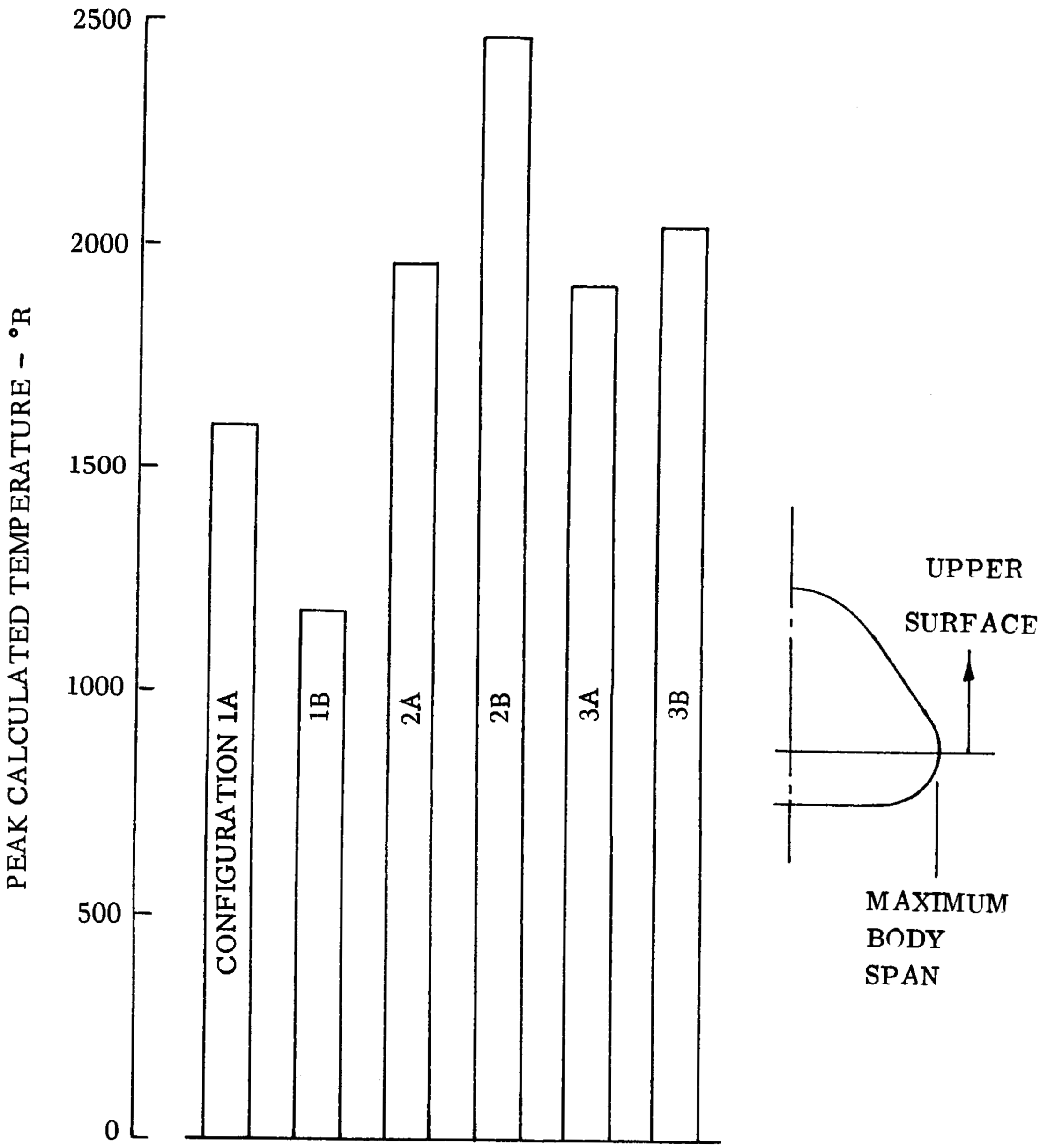



Figure 11. Upper Surface Temperature Summary

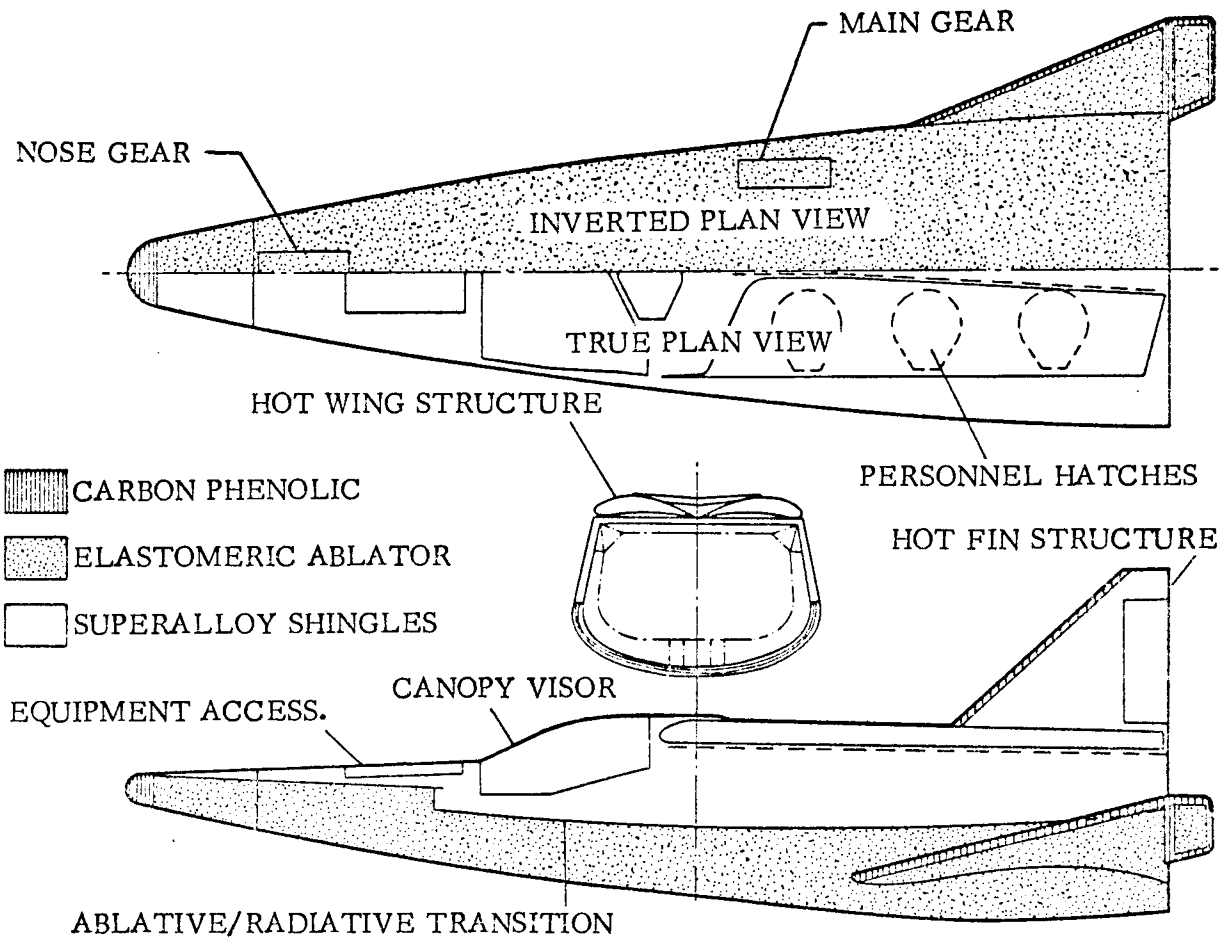



Figure 12. Schematic, Thermal Protection System, Vehicle 2A

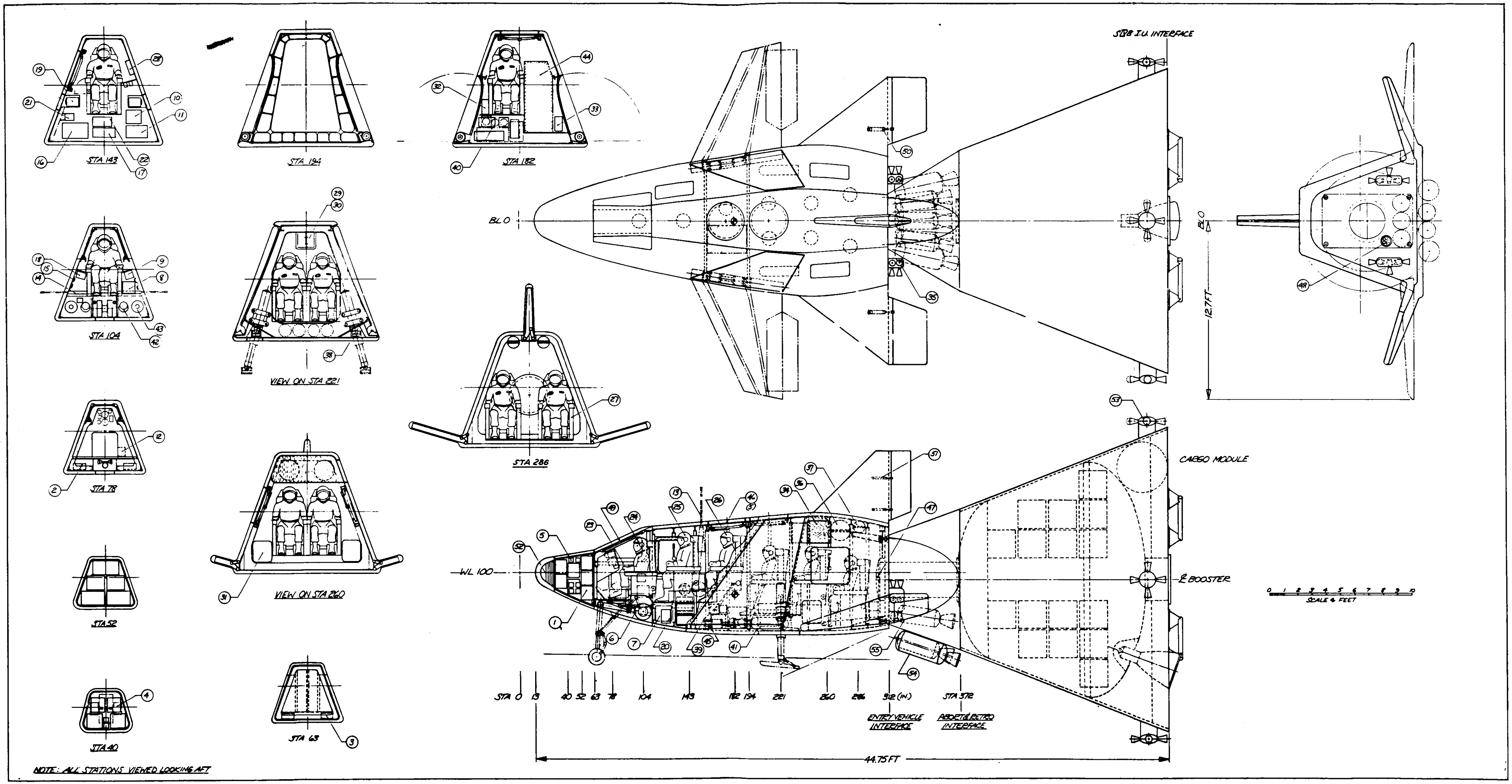



Figure 1a. General Arrangement Spacecraft 1A

## COMPONENT KEY -- ENTRY SPACECRAFT AND ADAPTERS

| Key Number | Component Name |
|---|---|
| 1 | Batteries |
| 2 | Inverters Main (2) |
| 3 | Inverters Control System (2) |
| 4 | Busses Main (2) |
| 5 | Solenoid Switches (10) |
| 6 | Nose Landing Gear and Compartment |
| 7 | Radar Beacons |
| 8 | Transceivers |
| 9 | Voice Control Center |
| 10 | Unified S-Band System |
| 11 | Telemetry Package |
| 12 | Digital Command Decoder |
| 13 | HF Whip Antenna |
| 14 | VHF Antennas (2) |
| 15 | S-Band Antennas (2) Radar Beacon Antennas (2) |
| 16 | Inertial Measuring Unit System |
| 17 | Digital Computer |
| 18 | Time Reference System |
| 19 | Horizon Sensors (2) |
| 20 | Radar Altimeter |
| 21 | Back-Up Guidance Package |
| 22 | Flight Control Electronics |
| 23 | Cockpit Controls & Instrument Panels |
| 24 | Pilot in Pressure Suit |
| 25 | Crewman in Pressure Suit |
| 26 | Passenger in Pressure Suits (7) |
| 27 | Seat, Personal Effects, Survival Kit, Hygiene, Intercomm Units & Suit Connectors |
| 28 | Maps, Manuals and Logs |
| 29 | Food and Container |
| 30 | Water and Container |
| 31 | Liferaft, Radio, and Equipment |
| 32 | Central Survival and Medical Kit |
| 33 | Repair and Tool Kit |
| 34 | Emergency Parachute System |
| 35 | Entry Attitude Control Thruster (10) or (12) |
| 36 | Entry Attitude Control Propellant Tanks (2) or (4) |
| 37 | Entry Attitude Control Pressurant Tanks (2) |
| 38 | Main Landing Gear |
| 39 | ECS - Thermal Control System |
| 40 | ECS - Contaminant Control System |
| 41 | ECS - Atmosphere Control and Storage System |
| 42 | Hydraulic Subsystem Pumps and DC Motors (2) |
| 43 | Hydraulic Reservoirs (2) and Manifold |
| 44 | Return Cargo Space |
| 45 | Variable Geometry Wing Extension Mechanism & Pivots |
| 46(X) | Exit and Entry Hatch and Total Number Provided |
| 47 | Hatch to Cargo Module |
| 48 | Entry Vehicle/Adapter-Module-Booster Umbilical Disconnect |
| 49 | Ejectable Canopy Visor |
| 50 | Elevon Actuators |
| 51 | Rudder Actuators |
| 52 | Ballast |
| 53 | DOACS Thruster Group (4) |
| 54 | Abort Rockets (2) |
| 55 | Retro Rockets (5) |
| 56 | Fuel Cells |
| 57 | Reactants For Fuel Cells |

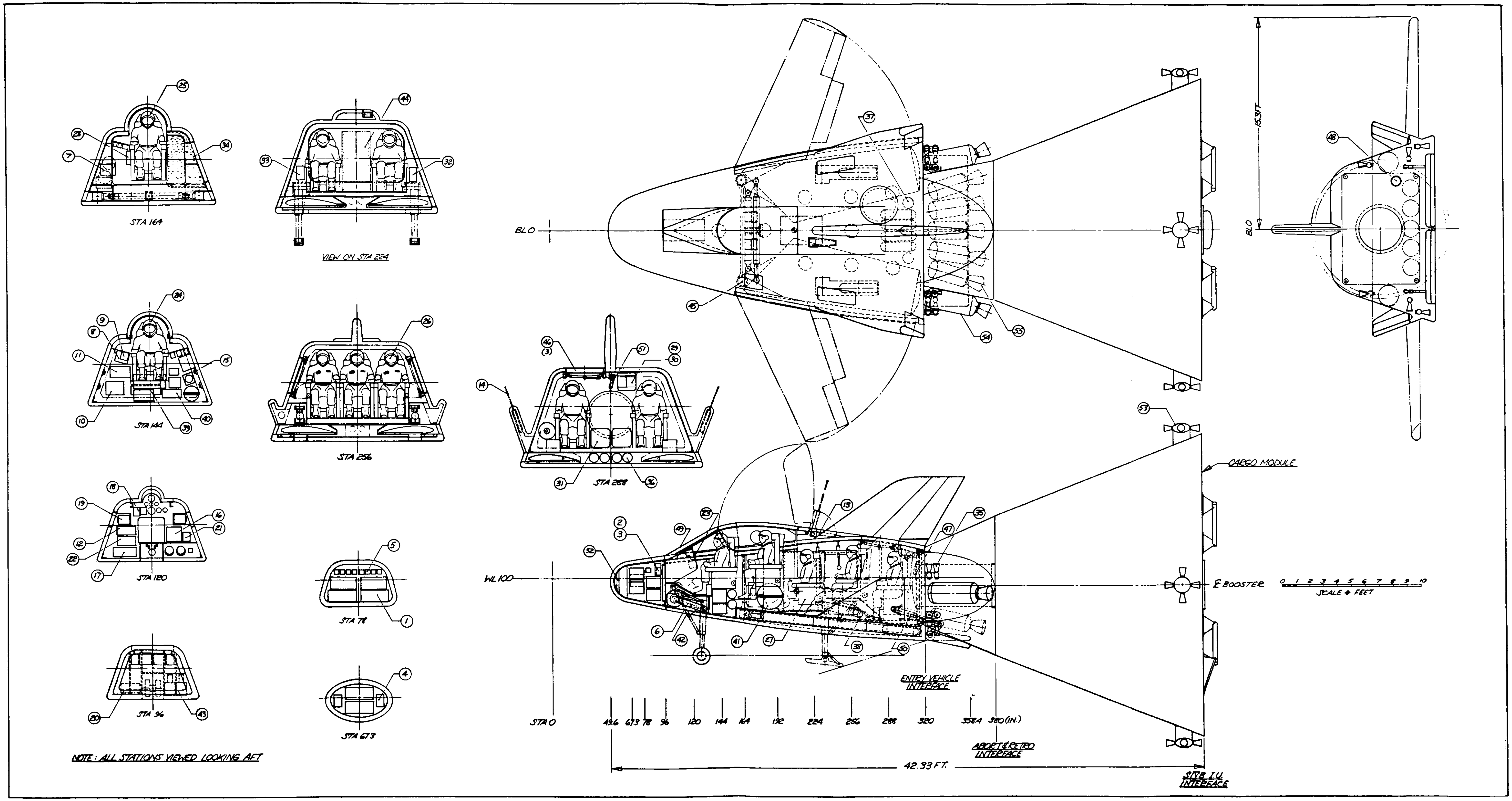



Figure 1b. General Arrangement Spacecraft 1B



FOLDOUT FRAME 1

## COMPONENT KEY -- ENTRY SPACECRAFT AND ADAPTERS

| Key Number | Component Name |
|---|---|
| 1 | Batteries |
| 2 | Inverters Main (2) |
| 3 | Inverters Control System (2) |
| 4 | Busses Main (2) |
| 5 | Solenoid Switches (10) |
| 6 | Nose Landing Gear and Compartment |
| 7 | Radar Beacons |
| 8 | Transceivers |
| 9 | Voice Control Center |
| 10 | Unified S-Band System |
| 11 | Telemetry Package |
| 12 | Digital Command Decoder |
| 13 | HF Whip Antenna |
| 14 | VHF Antennas (2) |
| 15 | S-Band Antennas (2) Radar Beacon Antennas (2) |
| 16 | Inertial Measuring Unit System |
| 17 | Digital Computer |
| 18 | Time Reference System |
| 19 | Horizon Sensors (2) |
| 20 | Radar Altimeter |
| 21 | Back-Up Guidance Package |
| 22 | Flight Control Electronics |
| 23 | Cockpit Controls & Instrument Panels |
| 24 | Pilot in Pressure Suit |
| 25 | Crewman in Pressure Suit |
| 26 | Passenger in Pressure Suits (7) |
| 27 | Seat, Personal Effects, Survival Kit, Hygiene, Intercomm Units & Suit Connectors |
| 28 | Maps, Manuals and Logs |
| 29 | Food and Container |
| 30 | Water and Container |
| 31 | Liferaft, Radio, and Equipment |
| 32 | Central Survival and Medical Kit |
| 33 | Repair and Tool Kit |
| 34 | Emergency Parachute System |
| 35 | Entry Attitude Control Thruster (10) or (12) |
| 36 | Entry Attitude Control Propellant Tanks (2) or (4) |
| 37 | Entry Attitude Control Pressurant Tanks (2) |
| 38 | Main Landing Gear |
| 39 | ECS - Thermal Control System |
| 40 | ECS - Contaminant Control System |
| 41 | ECS - Atmosphere Control and Storage System |
| 42 | Hydraulic Subsystem Pumps and DC Motors (2) |
| 43 | Hydraulic Reservoirs (2) and Manifold |
| 44 | Return Cargo Space |
| 45 | Variable Geometry Wing Extension Mechanism & Pivots |
| 46(X) | Exit and Entry Hatch and Total Number Provided |
| 47 | Hatch to Cargo Module |
| 48 | Entry Vehicle/Adapter-Module-Booster Umbilical Disconnect |
| 49 | Ejectable Canopy Visor |
| 50 | Elevon Actuators |
| 51 | Rudder Actuators |
| 52 | Ballast |
| 53 | DOACS Thruster Group (4) |
| 54 | Abort Rockets (2) |
| 55 | Retro Rockets (5) |
| 56 | Fuel Cells |
| 57 | Reactants For Fuel Cells |

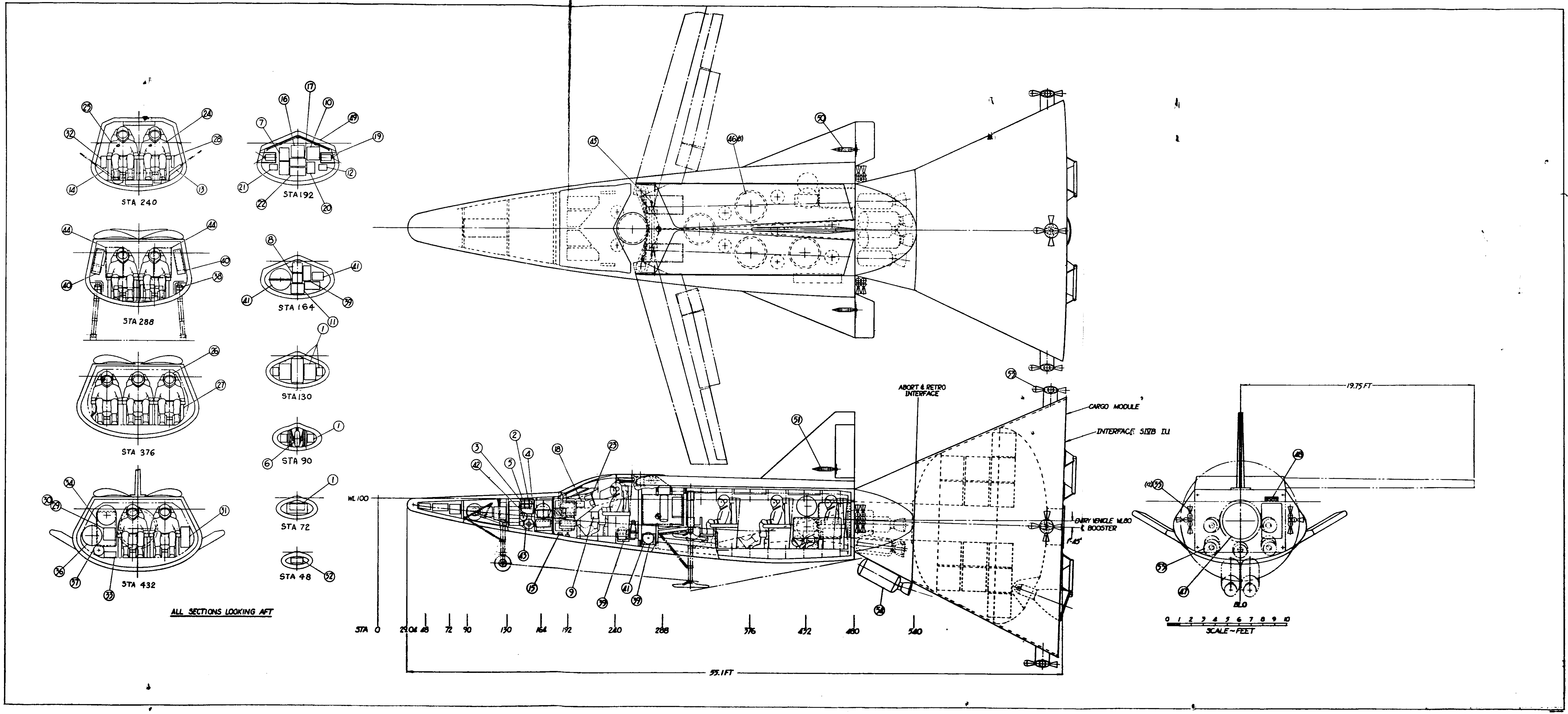



Figure 1c. General Arrangement Spacecraft 2A



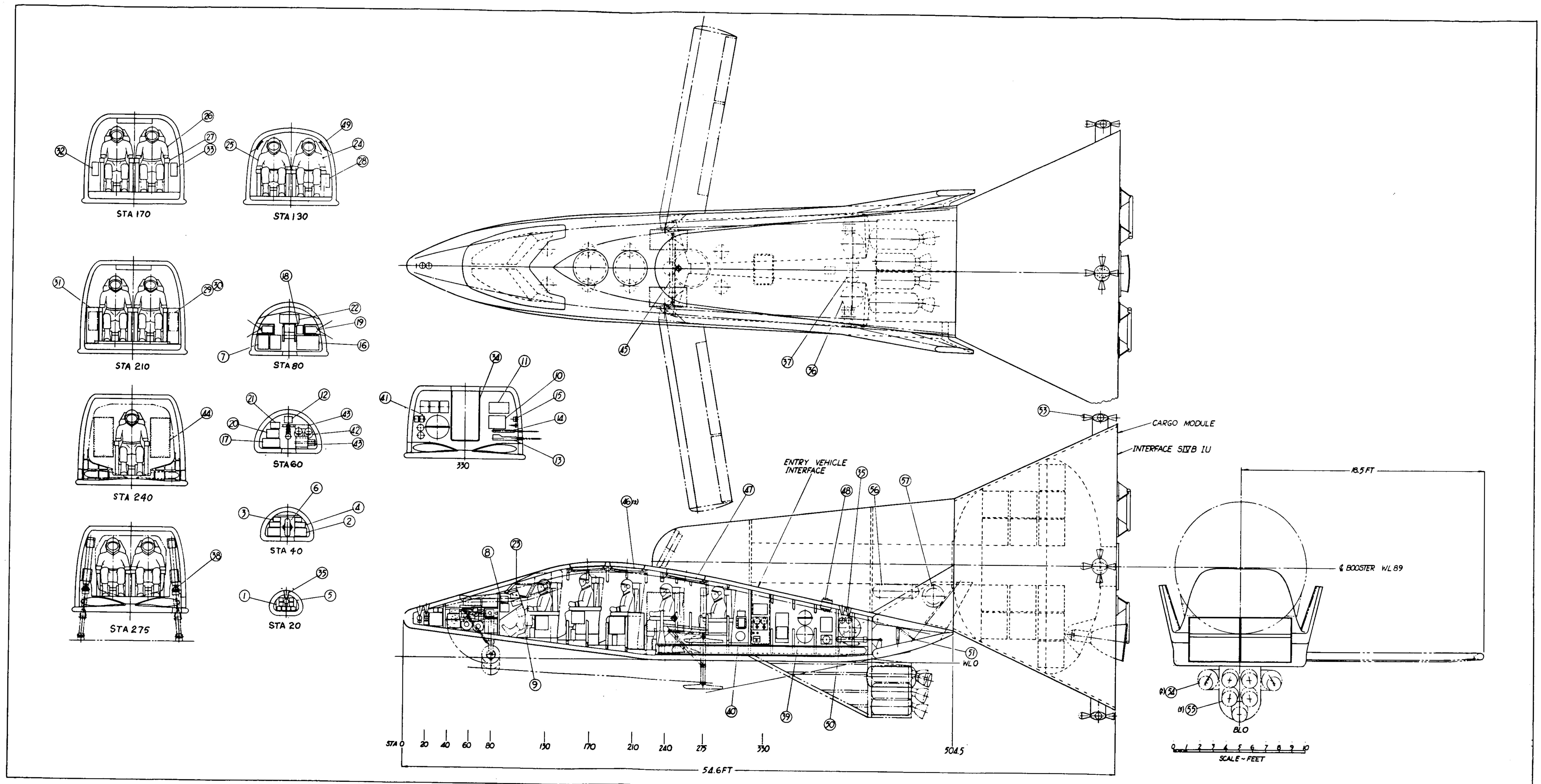
FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

COMPONENT KEY -- ENTRY SPACECRAFT AND ADAPTERS

| Key Number | Component Name |
|---|---|
| 1 | Batteries |
| 2 | Inverters Main (2) |
| 3 | Inverters Control System (2) |
| 4 | Busses Main (2) |
| 5 | Solenoid Switches (10) |
| 6 | Nose Landing Gear and Compartment |
| 7 | Radar Beacons |
| 8 | Transceivers |
| 9 | Voice Control Center |
| 10 | Unified S-Band System |
| 11 | Telemetry Package |
| 12 | Digital Command Decoder |
| 13 | HF Whip Antenna |
| 14 | VHF Antennas (2) |
| 15 | S-Band Antennas (2) Radar Beacon Antennas (2) |
| 16 | Inertial Measuring Unit System |
| 17 | Digital Computer |
| 18 | Time Reference System |
| 19 | Horizon Sensors (2) |
| 20 | Radar Altimeter |
| 21 | Back-Up Guidance Package |
| 22 | Flight Control Electronics |
| 23 | Cockpit Controls & Instrument Panels |
| 24 | Pilot in Pressure Suit |
| 25 | Crewman in Pressure Suit |
| 26 | Passenger in Pressure Suits (7) |
| 27 | Seat, Personal Effects, Survival Kit, Hygiene, Intercomm Units & Suit Connectors |
| 28 | Maps, Manuals and Logs |
| 29 | Food and Container |
| 30 | Water and Container |
| 31 | Liferaft, Radio, and Equipment |
| 32 | Central Survival and Medical Kit |
| 33 | Repair and Tool Kit |
| 34 | Emergency Parachute System |
| 35 | Entry Attitude Control Thruster (10) or (12) |
| 36 | Entry Attitude Control Propellant Tanks (2) or (4) |
| 37 | Entry Attitude Control Pressurant Tanks (2) |
| 38 | Main Landing Gear |
| 39 | ECS - Thermal Control System |
| 40 | ECS - Contaminant Control System |
| 41 | ECS - Atmosphere Control and Storage System |
| 42 | Hydraulic Subsystem Pumps and DC Motors (2) |
| 43 | Hydraulic Reservoirs (2) and Manifold |
| 44 | Return Cargo Space |
| 45 | Variable Geometry Wing Extension Mechanism & Pivots |
| 46(X) | Exit and Entry Hatch and Total Number Provided |
| 47 | Hatch to Cargo Module |
| 48 | Entry Vehicle/Adapter-Module-Booster Umbilical Disconnect |
| 49 | Ejectable Canopy Visor |
| 50 | Elevon Actuators |
| 51 | Rudder Actuators |
| 52 | Ballast |
| 53 | DOACS Thruster Group (4) |
| 54 | Abort Rockets (2) |
| 55 | Retro Rockets (5) |
| 56 | Fuel Cells |
| 57 | Reactants For Fuel Cells |




FOLDOUT FRAME 1

FOLDOUT FRAME 2

Figure 1d. General Arrangement Spacecraft 2B



FOLDOUT FRAME 3

## COMPONENT KEY -- ENTRY SPACECRAFT AND ADAPTERS

| Key Number | Component Name |
|---|---|
| 1 | Batteries |
| 2 | Inverters Main (2) |
| 3 | Inverters Control System (2) |
| 4 | Busses Main (2) |
| 5 | Solenoid Switches (10) |
| 6 | Nose Landing Gear and Compartment |
| 7 | Radar Beacons |
| 8 | Transceivers |
| 9 | Voice Control Center |
| 10 | Unified S-Band System |
| 11 | Telemetry Package |
| 12 | Digital Command Decoder |
| 13 | HF Whip Antenna |
| 14 | VHF Antennas (2) |
| 15 | S-Band Antennas (2) Radar Beacon Antennas (2) |
| 16 | Inertial Measuring Unit System |
| 17 | Digital Computer |
| 18 | Time Reference System |
| 19 | Horizon Sensors (2) |
| 20 | Radar Altimeter |
| 21 | Back-Up Guidance Package |
| 22 | Flight Control Electronics |
| 23 | Cockpit Controls & Instrument Panels |
| 24 | Pilot in Pressure Suit |
| 25 | Crewman in Pressure Suit |
| 26 | Passenger in Pressure Suits (7) |
| 27 | Seat, Personal Effects, Survival Kit, Hygiene, Intercomm Units & Suit Connectors |
| 28 | Maps, Manuals and Logs |
| 29 | Food and Container |
| 30 | Water and Container |
| 31 | Liferaft, Radio, and Equipment |
| 32 | Central Survival and Medical Kit |
| 33 | Repair and Tool Kit |
| 34 | Emergency Parachute System |
| 35 | Entry Attitude Control Thruster (10) or (12) |
| 36 | Entry Attitude Control Propellant Tanks (2) or (4) |
| 37 | Entry Attitude Control Pressurant Tanks (2) |
| 38 | Main Landing Gear |
| 39 | ECS - Thermal Control System |
| 40 | ECS - Contaminant Control System |
| 41 | ECS - Atmosphere Control and Storage System |
| 42 | Hydraulic Subsystem Pumps and DC Motors (2) |
| 43 | Hydraulic Reservoirs (2) and Manifold |
| 44 | Return Cargo Space |
| 45 | Variable Geometry Wing Extension Mechanism & Pivots |
| 46(X) | Exit and Entry Hatch and Total Number Provided |
| 47 | Hatch to Cargo Module |
| 48 | Entry Vehicle/Adapter-Module-Booster Umbilical Disconnect |
| 49 | Ejectable Canopy Visor |
| 50 | Elevon Actuators |
| 51 | Rudder Actuators |
| 52 | Ballast |
| 53 | DOACS Thruster Group (4) |
| 54 | Abort Rockets (2) |
| 55 | Retro Rockets (5) |
| 56 | Fuel Cells |
| 57 | Reactants For Fuel Cells |

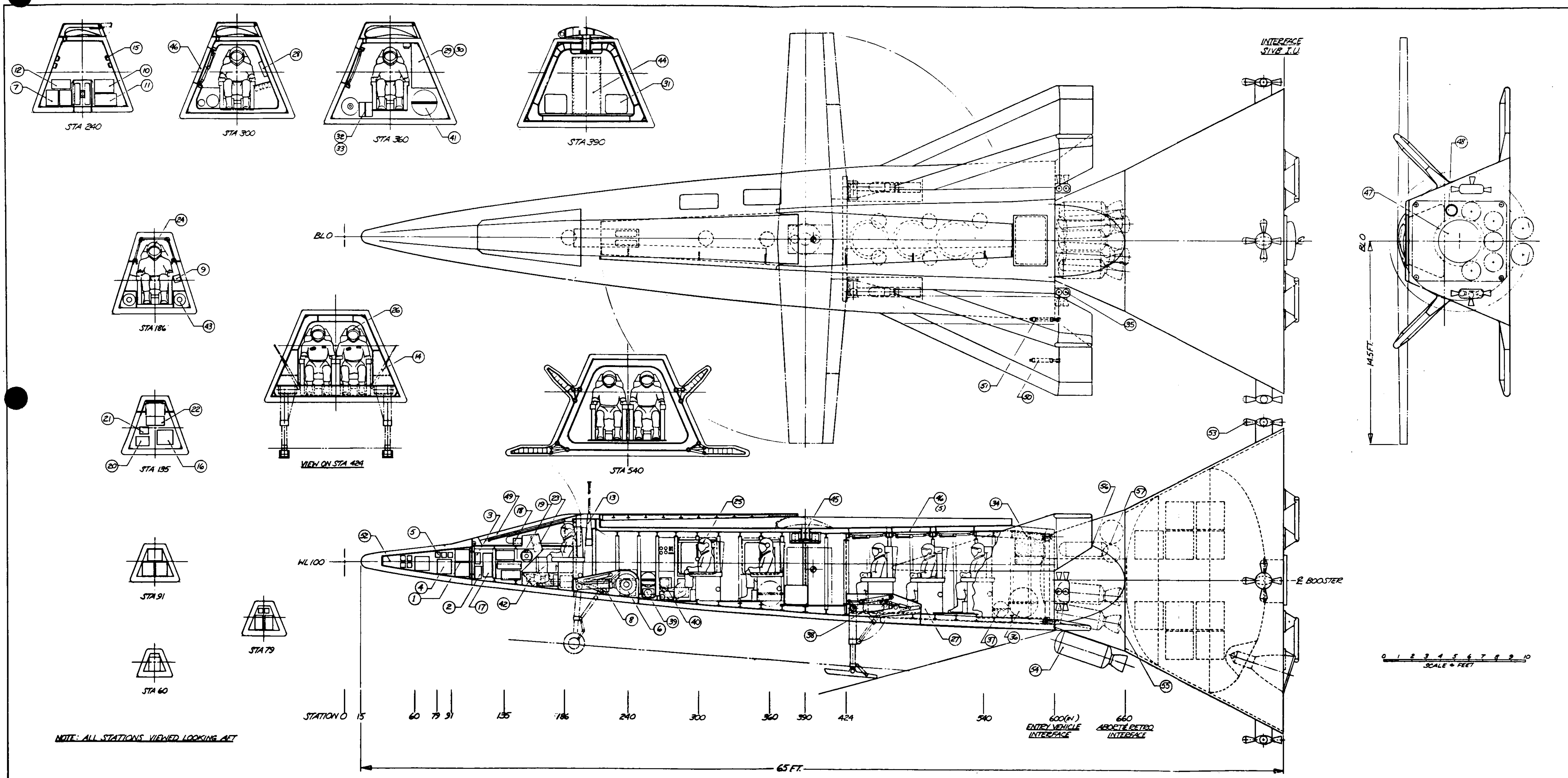



Figure 1e. General Arrangement Spacecraft 3A

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

## COMPONENT KEY -- ENTRY SPACECRAFT AND ADAPTERS

| Key Number | Component Name |
|---|---|
| 1 | Batteries |
| 2 | Inverters Main (2) |
| 3 | Inverters Control System (2) |
| 4 | Busses Main (2) |
| 5 | Solenoid Switches (10) |
| 6 | Nose Landing Gear and Compartment |
| 7 | Radar Beacons |
| 8 | Transceivers |
| 9 | Voice Control Center |
| 10 | Unified S-Band System |
| 11 | Telemetry Package |
| 12 | Digital Command Decoder |
| 13 | HF Whip Antenna |
| 14 | VHF Antennas (2) |
| 15 | S-Band Antennas (2) Radar Beacon Antennas (2) |
| 16 | Inertial Measuring Unit System |
| 17 | Digital Computer |
| 18 | Time Reference System |
| 19 | Horizon Sensors (2) |
| 20 | Radar Altimeter |
| 21 | Back-Up Guidance Package |
| 22 | Flight Control Electronics |
| 23 | Cockpit Controls & Instrument Panels |
| 24 | Pilot in Pressure Suit |
| 25 | Crewman in Pressure Suit |
| 26 | Passenger in Pressure Suits (7) |
| 27 | Seat, Personal Effects, Survival Kit, Hygiene, Intercomm Units & Suit Connectors |
| 28 | Maps, Manuals and Logs |
| 29 | Food and Container |
| 30 | Water and Container |
| 31 | Liferaft, Radio, and Equipment |
| 32 | Central Survival and Medical Kit |
| 33 | Repair and Tool Kit |
| 34 | Emergency Parachute System |
| 35 | Entry Attitude Control Thruster (10) or (12) |
| 36 | Entry Attitude Control Propellant Tanks (2) or (4) |
| 37 | Entry Attitude Control Pressurant Tanks (2) |
| 38 | Main Landing Gear |
| 39 | ECS - Thermal Control System |
| 40 | ECS - Contaminant Control System |
| 41 | ECS - Atmosphere Control and Storage System |
| 42 | Hydraulic Subsystem Pumps and DC Motors (2) |
| 43 | Hydraulic Reservoirs (2) and Manifold |
| 44 | Return Cargo Space |
| 45 | Variable Geometry Wing Extension Mechanism & Pivots |
| 46(X) | Exit and Entry Hatch and Total Number Provided |
| 47 | Hatch to Cargo Module |
| 48 | Entry Vehicle/Adapter-Module-Booster Umbilical Disconnect |
| 49 | Ejectable Canopy Visor |
| 50 | Elevon Actuators |
| 51 | Rudder Actuators |
| 52 | Ballast |
| 53 | DOACS Thruster Group (4) |
| 54 | Abort Rockets (2) |
| 55 | Retro Rockets (5) |
| 56 | Fuel Cells |
| 57 | Reactants For Fuel Cells |

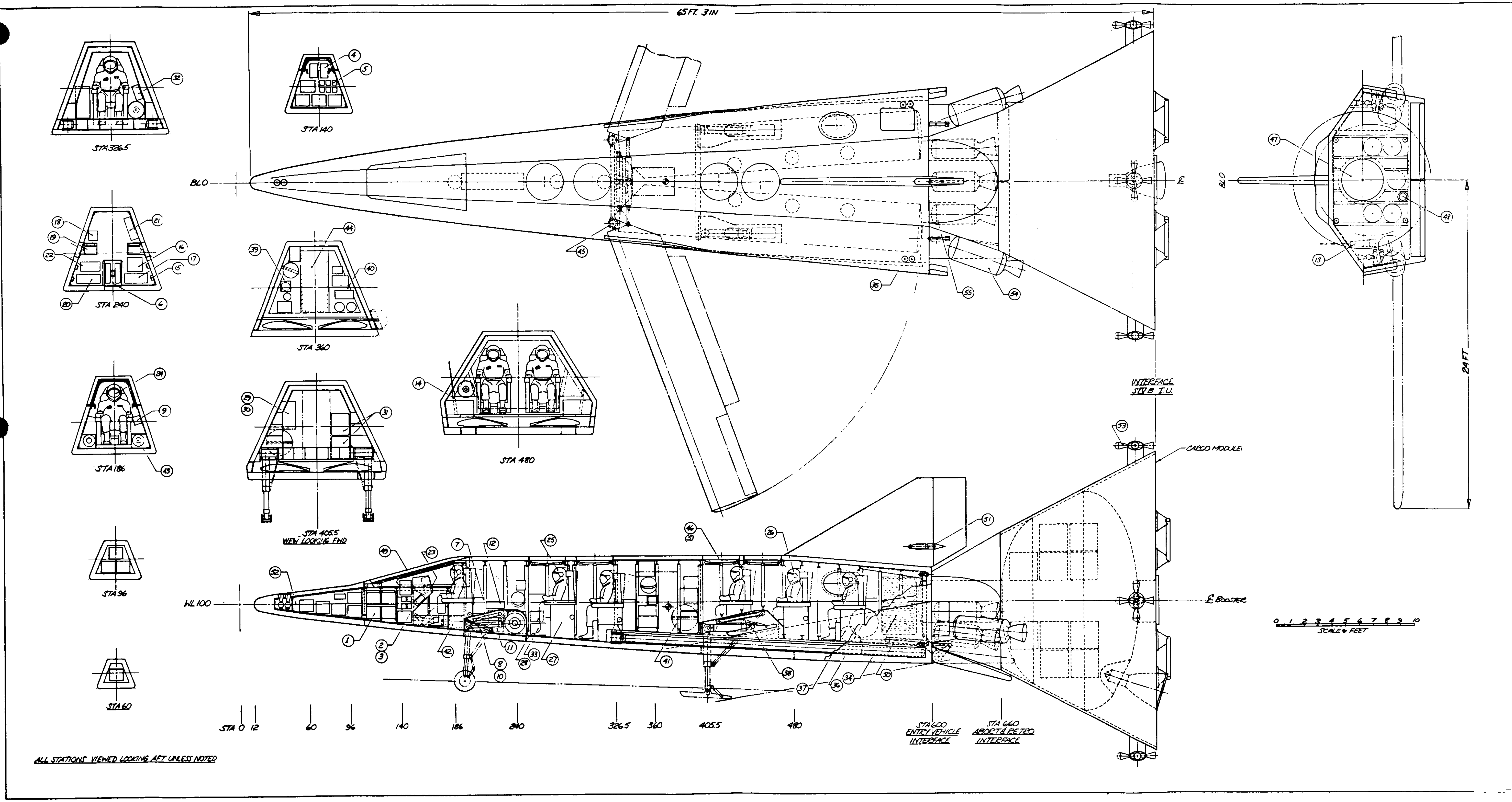



Figure 1f. General Arrangement Spacecraft 3B

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

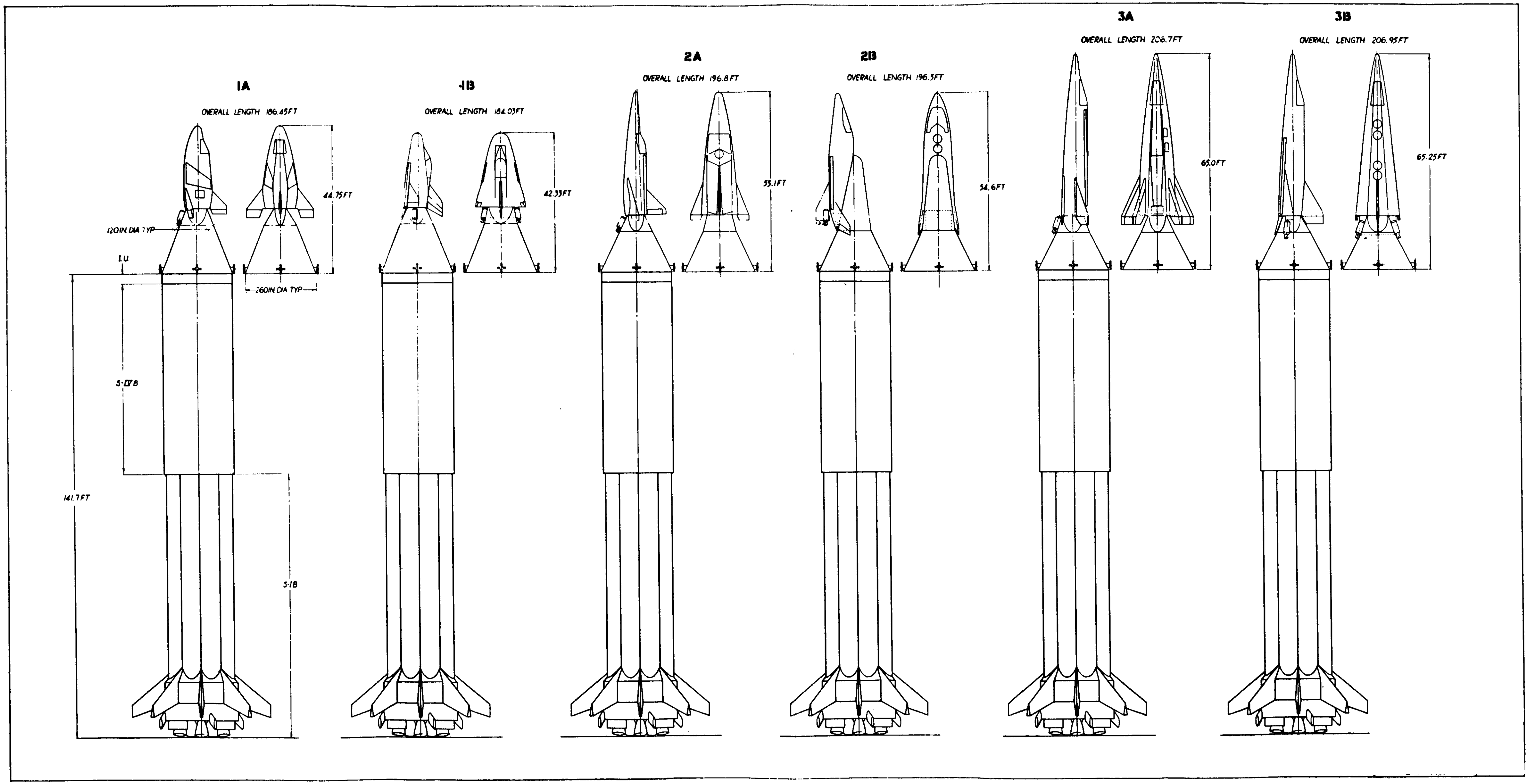
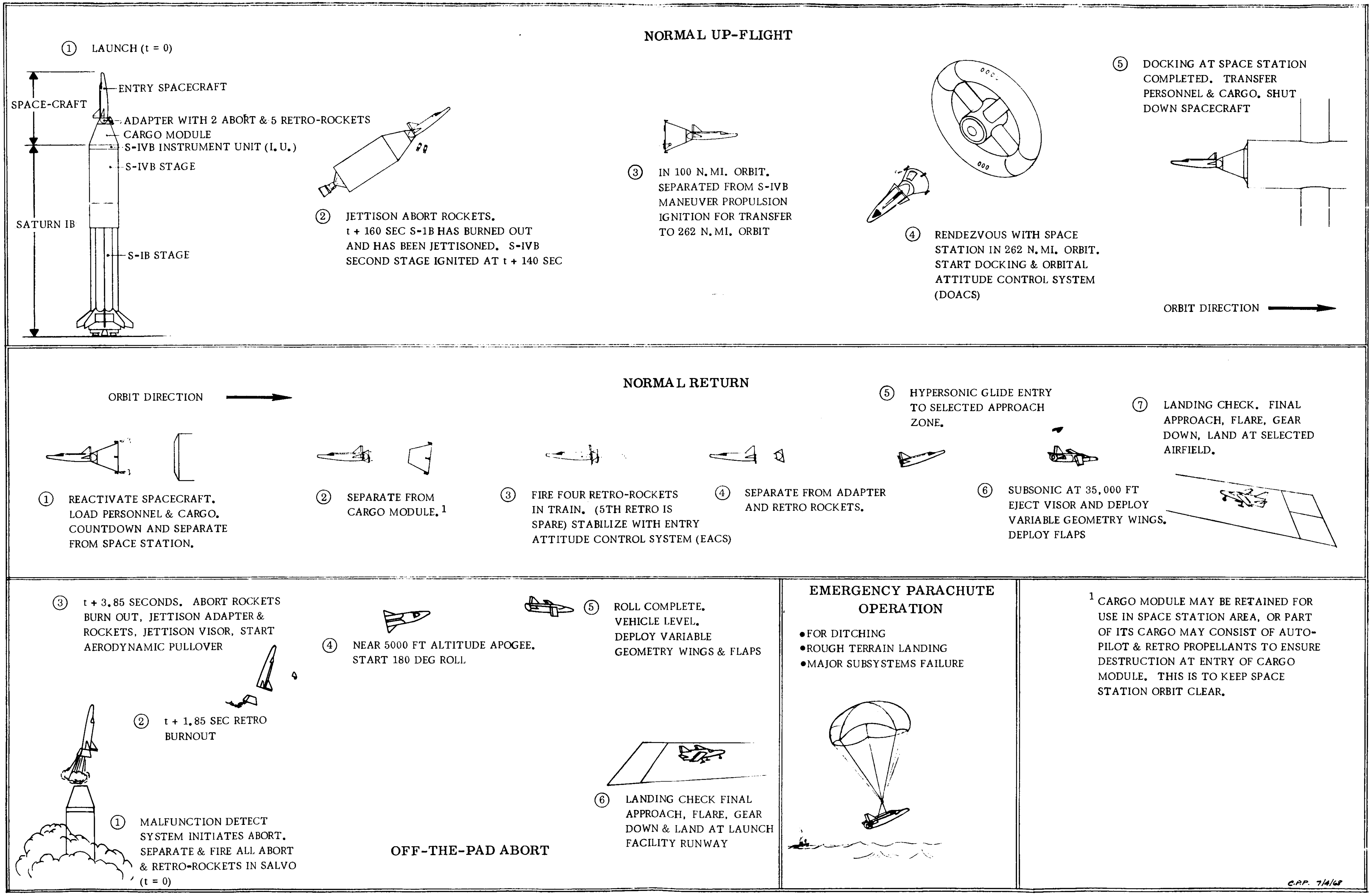



Figure 2. Final Spacecraft on Saturn 1B Booster



FOLDOUT FRAME 1

FOLDOUT FRAME 2




FOLDOUT FRAME 1

Figure 3. Operational Sequence of Major Events

FOLDOUT FRAME 2

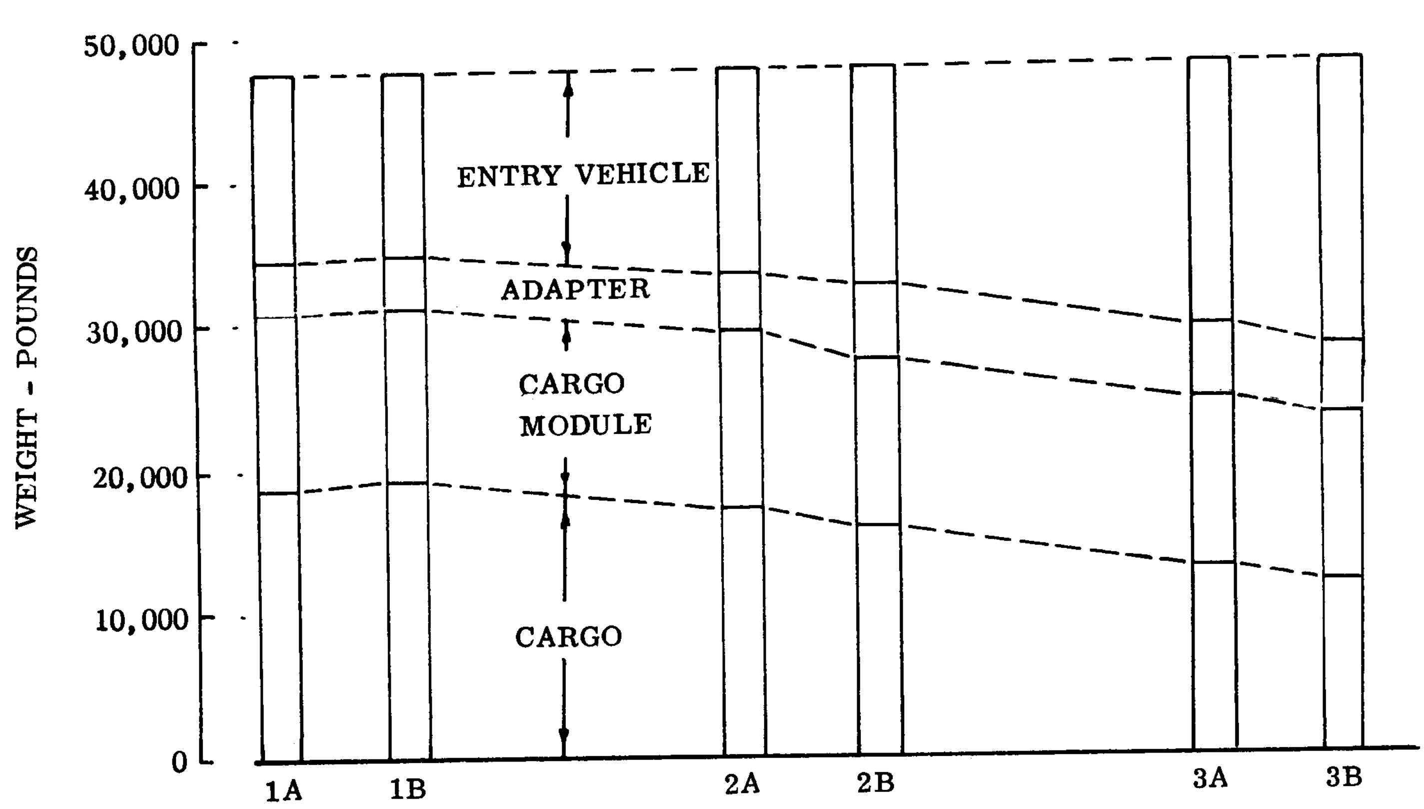



Figure 4. Overall Weights, Uprated S-1B